CANTILEVER RETICLE STAGE FOR ELECTRON BEAM PROJECTION LITHOGRAPHY SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

The present invention claims priority of provisional U.S. Patent Application No. 60/226,409, filed August 18, 2000, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of Invention

The present invention relates generally to lithography. More particularly, the present invention relates to a reticle stage for use in an electron beam projection lithography system.

2. Description of the Related Art

Lithography processes, *e.g.*, photo-lithography processes, are integral to the fabrication of wafers and, hence, semiconductor chips. Conventional systems used for lithography include optical lithography systems and electron beam projection systems. Many electron beam projection systems may use a direct writing process to "write" on wafers. However, direct writing processes are often relatively slow, as will be appreciated by those skilled in the art.

In order to increase the speed at which wafers may be written to, electron beam projection systems, as well as optical lithography systems, may project beams of finite area through patterns. The patterns are generally resident on a reticle, which effectively serves as a mask or a negative for a wafer. For an electron beam projection system, a relatively broad beam of electrons may be collimated and provided to a reticle, which may be a silicon wafer, *e.g.*, a wafer that is suitable for scattering with angular limitation projection electron beam lithography or a stencil-type wafer. Typically, rather than absorbing the beam, the pattern deflects portions of the beam in order to prevent electrons from being ultimately focused onto a wafer.

Figure 1 is a block diagram representation of the overall configuration of the lens system of an electron beam projection system. As shown, a lens system 102 includes an illumination lens 110, *e.g.*, an illumination column, and a projection lens 114, *e.g.*, a projection column. An electron beam is arranged to pass through illumination lens 110 to a reticle 122. As the beam "hits" reticle 122, portions of the beam are allowed to pass through reticle 122, while other portions of the beam may be prevented from passing through reticle 122, *e.g.*, other portions of the beam may be scattered to prevent the portions from being focused onto a wafer 118. That is, as will be appreciated by those skilled in the art, reticle 122 acts as a mask and effectively masks out part of the beam, *i.e.*, a pattern of electrons passes through reticle 122. Projection lens 114 is arranged to project the pattern of electrons onto wafer 118.

In general, a gap 124, *i.e.*, space, between illumination lens 110 and projection lens 114 is limited. By way of example, gap 124 may be approximately 60 millimeters in height, *i.e.*, along z-axis 126. As such, reticle 122, as well as any structure which supports reticle 122, must be sized to be accommodated within gap 124.

In a conventional optical system, a stage (not shown) is often used to position wafer 118 as appropriate below illumination lens 110, reticle 122, and projection lens 114. Such a stage, *e.g.*, a wafer stage, is conventionally arranged for use in a "step and repeat" configuration. In other words, a wafer stage may be positioned vertically along a z-axis 126, or stepped, until the wafer stage is at a height which is consistent with enabling the wafer stage to be moved along a x-axis 130 below projection lens 114. When it becomes necessary to reposition the wafer stage, then the wafer stage may be stepped along x-axis 130 out from under projection lens 114, stepped along y-axis 128, and stepped along x-axis 130 back under projection lens 114. Alternatively, the wafer stage may be stepped along only one of x-axis 130 and y-axis 128.

Electron beam projection systems are often used in lieu of optical systems because a lens system associated with an electron beam projection system may

dynamically move a projection image to follow a stage, which is generally not possible with an optical system, as will be appreciated by those skilled in the art. In addition, electron beam lens systems typically correct for relatively small errors in relative stage positions, whereas optical systems generally do not.

The throughput associated with electron beam projection systems has generally been limited, due at least in part to the fact that electron beam systems operate in a vacuum. Further, within electron beam projection systems, the implementation of a step and scan configuration may be difficult. Specifically, implementing a step and scan configuration with respect to a stage which scans reticles, *e.g.*, a reticle stage, is difficult, as electron beam projection systems have specific requirements which are not requirements for typical optical lithography systems. By way of example, an electron beam projection system generally must operate in a high vacuum environment. Further, an electron beam projection system may not include moving magnets, as moving magnets cause the magnetic field associated with the electron beam projection system to change. An electron beam projection system also may not having moving iron structures, due to the fact that moving iron dynamically alters the static magnetic fields around an electron beam lens, as will be appreciated by those skilled in the art. Finally, an electron beam projection system may not have metal parts which move such that eddy currents are generated in static magnetic fields with concomitant additional varying magnetic fields.

Therefore, what is needed is a method and an apparatus for enabling reticles to be positioned efficiently within an electron beam projection system. That is, what is desired is a method and an apparatus for enabling reticles to be stepped and scanned as a part of an electron beam projection system.

SUMMARY OF THE INVENTION

The present invention relates to a high performance reticle stage that is suitable for use in an electron beam projection lithography system. According to one aspect of the present invention, a scanning apparatus that is suitable for use in an

electron beam projection system includes a first guide beam and a translational structure. The first guide beam includes a first vacuum chamber and a second vacuum chamber which are in fluid communication with a first airbearing structure that is a part of the translational structure. The translational structure is generally arranged to move linearly with respect to the first guide beam, which is at least partially disposed within the translational structure. In one embodiment, the first guide beam includes four contact sides, and the first airbearing structure includes air pads arranged to substantially contact each of the four contact sides.

In another embodiment, the scanning apparatus includes a second guide beam which has at least two sides, *e.g.*, that has four sides. The second guide beam is oriented to be substantially perpendicular to the first guide beam, but is not arranged to directly contact the first guide beam. In such an embodiment, the second guide beam is at least partially disposed within a second airbearing structure that is substantially rigidly or fixably coupled to the first guide beam. The second airbearing structure includes air pads arranged to substantially contact two opposing sides of the four sides of the second guide beam.

According to another aspect of the present invention, an electron beam projection lithography system includes an illumination column, a projection column which is separated from the illumination column by a distance, and a stage structure. The stage structure includes a portion that is arranged to be manipulated within the distance and an airbearing structure that is mechanically coupled to the portion. The portion is arranged to support at least one reticle through which an electron beam may pass from the illumination column to the projection column. The airbearing structure is arranged to enable the portion to be scanned within the distance. In one embodiment, the portion is a reticle plate that is cantilevered off of the airbearing structure. In such an embodiment, the reticle plate may be a substantially hollow ceramic structure.

In another embodiment, the electron beam projection lithography system also includes a guide structure, a magnet track, and a coil. The coil may be coupled to the airbearing structure such that when the coil moves linearly within the magnet track

such that the coil is substantially always within the magnet track, the movement of the coil causes the airbearing structure to move linearly over the guide structure. In such an embodiment, the movement of the coil further causes the portion to be scanned within the distance.

According to still another aspect of the present invention, a stage apparatus that is suitable for scanning in an electron beam projection system which has an associated vacuum environment includes a first guide beam, a translational structure with a first airbearing structure and a cantilevered reticle plate, and a linear motor. The linear motor is coupled to the first airbearing structure and does not alter a magnetic field associated with the electron beam projection system when the linear motor causes the translational structure to scan over the first guide beam. The linear motor is further arranged to drive through a center of gravity of the stage apparatus.

In one embodiment, the stage apparatus also includes a second guide beam that has at least two sides and is substantially perpendicular to the first guide beam, as well as a second airbearing structure which is substantially rigidly coupled to the first guide beam. The second airbearing structure includes air pads arranged to substantially only contact a top side and a bottom side of the four sides of the second guide beam. In such an embodiment, the stage apparatus may further include a third guide beam and a third airbearing structure that is arranged to move translationally with respect to the third guide beam. The third airbearing structure is coupled to the first guide beam such that the translational structure may exhibit a yawing motion.

These and other advantages of the present invention will become apparent upon reading the following detailed descriptions and studying the various figures of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

Figure 1 is a block diagram representation of the overall configuration of the lens system of an electron beam projection system

Figure 2 is a block diagram representation of the overall configuration of the lens system of an electron beam projection system in accordance with an embodiment of the present invention.

Figure 3 is a representation of a stage with a cantilevered reticle structure in accordance with a first embodiment of the present invention.

Figure 4a is a representation of a reticle cantilever structure, *e.g.*, reticle cantilever structure 208 of Figure 3, in accordance with an embodiment of the present invention.

Figure 4b is a diagrammatic three-dimensional representation of an airbearing box, *e.g.*, y-airbearing box 306 of Figure 3, in accordance with an embodiment of the present invention.

Figure 4c is a diagrammatic cut-away representation of an airpad of an airbearing box, *e.g.*, y-airbearing box 306 of Figure 3, in accordance with an embodiment of the present invention.

Figure 4d is a diagrammatic three-dimensional representation of a beam, *e.g.*, beam 310 of Figure 3, in accordance with an embodiment of the present invention.

Figure 4e is a diagrammatic cross-sectional representation of a cantilever structure, *e.g.*, reticle cantilever structure 208 of Figure 3, and a magnet track in accordance with an embodiment of the present invention.

Figure 5a is a diagrammatic three-dimensional representation of an airbearing box, *e.g.*, x-airbearing box 348b of Figure 3, and a beam in accordance with an embodiment of the present invention.

Figure 5b is a diagrammatic three-dimensional representation of an airbearing box, *e.g.*, x-airbearing box 348b of Figure 3, in accordance with an embodiment of the present invention.

Figure 5c is a diagrammatic representation of a coupler, *e.g.*, coupler 354 of Figure 3, in accordance with an embodiment of the present invention.

Figure 5d is a diagrammatic three-dimensional representation of an airbearing box, *e.g.*, x-airbearing box 348a of Figure 3, and a beam in accordance with an embodiment of the present invention.

Figure 5e is a diagrammatic three-dimensional representation of an airbearing box, *e.g.*, x-airbearing box 348a of Figure 3, in accordance with an embodiment of the present invention.

Figure 6 is a three-dimensional representation of a scanning system which includes a reticle cantilever structure, *e.g.*, reticle cantilever structure 208 of Figure 3, in accordance with an embodiment of the present invention.

Figure 7 is a three-dimensional representation of a scanning system which includes a reticle cantilever structure in accordance with a second embodiment of the present invention.

Figure 8 is a three-dimensional representation of the back side of a scanning system, *e.g.*, scanning system 702 of Figure 7, in accordance with the second embodiment of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

A reticle stage for scanning within an electron beam projection system generally must be arranged to operate within the high vacuum environment, *e.g.*, a vacuum environment with a vacuum level of approximately 1e-6 Torr, associated with the electron beam projection system. Generally, a suitable reticle stage for scanning within an electron beam projection system would be arranged to minimize the disturbance to the magnetic fields in the path of the electron beam. Hence, the reticle stage should minimize the amount of associated moving magnets and moving iron which disturb the magnetic fields.

Other conductors, *e.g.*, metals, which move in magnetic fields associated with a gap between an illumination lens and a projection lens have a less pronounced impact on the magnetic fields. That is, other conductors have a secondary impact on the magnetic fields in that moving conductors generate eddy currents within themselves which then create their own magnetic fields. In general, the degree to which these additional magnetic fields are problematic depends upon the size, orientation, velocity and conductivity of the conductive material, as well as the magnetic field strength and proximity of the additional magnetic fields to an electron

beam path. Additional considerations regarding the secondary impact on magnetic fields include, but are not limited to, magnetic shielding provided by an electron beam column and features associated with a vacuum chamber.

In one embodiment, a reticle stage may include a cantilevered table or plate which supports a plurality of reticles and is coupled to an air bearing which enables the reticle stage to scan. The table may be sized to be accommodated between an illumination lens column and a projection lens column. Additionally, the table may be formed from a ceramic material. Generally, the use of air bearings, in addition to the use of a table formed from a ceramic material, significantly reduces issues associated with moving metals. To further reduce the effect of moving metals, the table may be arranged to be held together by very small metal screws.

Linear motors used to enable the reticle stage to move may be arranged such that associated magnet tracks are substantially stationary, thereby effectively eliminating issues associated with moving magnets. The linear motors may further be arranged to "drive" through the centers of mass of moving parts, such as the reticle stage. Driving through the center of gravity may be desirable for many reasons including, but not limited to, the minimization of undesirable moments on the overall stage when moving parts accelerate. While the linear motor coils are relatively large conductors, the linear motor coils may be positioned relatively far from an electron beam column, and may be well shielded by the magnetic tracks associated with the linear motors. Further, while the linear motor coils may generate relatively large magnetic fields when energized, during scanning, the amount of current used for accelerating may be small and, as a result, have very little effect on an electron beam.

Referring to Figure 2, a block diagram representation of a scanning reticle stage suitable for use in an electron beam projection system will be described in accordance with an embodiment of the present invention. A scanning reticle stage 208 is arranged to scan a reticle 222, or reticles, within a gap 224 that is defined between an illumination lens 210 and a projection lens 214. In one embodiment, reticle stage 208 and, hence, reticle 222, may be arranged such that reticle 222 scans in one direction, *e.g.*, along a y-axis 228, and steps in another direction, *e.g.*, along a

x-axis 236. Electrons that pass through illumination lens 210 and reticle 222 to projection lens 214 may then be projected onto wafer 218 such that a pattern defined by reticle 222 is formed on wafer 218.

As will be appreciated by those skilled in the art, reticle stage 208 may be arranged to accommodate multiple reticles, *e.g.*, two or three reticles, which include complementary patterns of an entire chip circuit which is to be formed on wafer 218. In one embodiment, an entire chip circuit may be formed on a chip which is approximately 25 millimeters (mm) by 33 millimeters in size. The size of reticle cantilever structure 301 as well as the stroke of reticle stage 208 along y-axis 228 may be relatively large. By way of example, in some systems, the size of the stroke along y-axis 228 may be up to approximately 600 mm. Similarly, the size and stroke of reticle stage 208 may also be relatively large along x-axis 230, *e.g.*, the size of the stroke along x-axis 230 may be up to approximately 170 mm. The size of a stroke is typically dependent upon the size and the configuration of reticles. Specifically, each reticle that is supported by reticle stage 208 may have multiple scanning stripes, thereby effectively requiring that the stroke of reticle stage 208 be sufficient to cover the scanning stripes.

Reticle stage 208 may be formed to include a cantilever structure, as shown in Figure 3. Figure 3 is a diagrammatic representation of a reticle stage which supports a cantilevered, scanning reticle table in accordance with a first embodiment of the present invention. Reticle stage 208 includes a cantilever structure or a scanning y-stage 301. Cantilever structure or scanning y-stage 301 may include a plate 300, *e.g.*, a table or a cantilever, which includes openings 302 that are sized to accommodate reticles (not shown). Although plate 300 is shown as including three openings 302, or chucks, plate 300 may generally include any number of openings 302, as for example two openings. The number of openings 302 may be determined, for instance, on the size of a pattern area and the number of patterns needed to fit a chip on a wafer. Typically, openings 302 are aligned such that reticles may be aligned in a scanning direction, *i.e.*, along a y-axis 328, to enable travel along x-axis 330 to be substantially minimized. It should be appreciated, however, that the orientation of openings 302

may vary widely. By way of example, openings 302 may be oriented in a substantially square pattern.

Cantilever structure 301, which includes cantilever or table 300, may be formed from substantially any non-metallic material which has acceptable outgassing characteristics for a relatively high vacuum. By way of example, cantilever structure 301 may be formed as a ceramic structure. The formation of cantilever structure 301 from ceramic enables cantilever structure 301 to move within an electron beam projection system without significantly affecting the magnetic fields associated with the electron beam projection system. In order to substantially maximize the stiffness-to-weight ratio associated with cantilever structure 301, table 300 may be formed as a hollow ceramic structure.

In general, at least one or two sides 340 and front edge 344 of plate 300 may include mirrored surfaces, *i.e.*, reticle stage mirrors. The mirrored surfaces enable laser interferometer beams to be substantially reflected off of sides 340 and front edge 344 to enable positioning measurements to be made with respect to plate 300 or, more generally, cantilever structure 301. For example, front edge 344 may be used to facilitate the measurement of a linear position of stage 208 in x-direction 330, as well as measurements of a rotational position of stage 208 about y-axis 328 and z-axis 326, *i.e.*, an angle θy 352 and an angle θz 350, respectively. Similarly, sides 340 may be used to measure a linear position of stage 208 along y-axis 328, and rotational positions about z-axis 326, *i.e.*, an angle θz 350, and x-axis 330, *i.e.*, angle θx 356.

As shown, cantilever structure 301 includes an airbearing box 306 that is arranged to move along a beam guide 310 in a scanning direction, *i.e.*, a y-direction 328. Specifically, plate 300 is coupled to airbearing box 306 such that the movement of airbearing box 306 causes plate 300 to scan, as for example within a gap between an illumination lens and a projection lens. Airbearing box 306 or, more specifically, y-airbearing box 306, will be described below with reference to Figures 4a. It should be appreciated that compared to an airbearing stage which is operating in a non-vacuum environment, particular features are generally needed to minimize gas leakage from airbearing box 306 into the vacuum chamber which houses reticle stage

208. Minimizing gas leakage typically prevents the amount of vacuum that is achievable from being significantly reduced.

In general, exhaust flow of air from y-airbearing box 306 may be ducted through the interior of beam 310. As mentioned above, y-airbearing box 306 is arranged to slide along beam 310 along y-axis 328. While being free to move along y-axis 328, y-airbearing box 306 is constrained, or "stiff," along x-axis 330 and z-axis 326. Further, y-airbearing box 306 is constrained from being able to rotate relative to guide beam 310. In other words, y-airbearing box 306 may not rotate about x-axis 330, y-axis 328, or z-axis 326. Guide beam 310 will be described below with reference to Figure 4d.

A spacer 314 is arranged to hold a coil assembly 318 for a linear motor with respect to y-airbearing box 306 such that coil assembly 318 may cause y-airbearing box 306 to scan. In one embodiment, coil assembly 318 includes two coils, although it should be understood that coil assembly 318 may generally include any number of coils. The use of two coils in coil assembly 318, where one coil is positioned above y-airbearing 306 and one coil is positioned below y-airbearing 306, enables the net driving force on y-airbearing 306 to be aligned closely with the center of gravity of cantilever structure 301 and beam 310. Coil assembly 318, spacer 314, and magnet tracks (not shown) that at least partially surround coil assembly 318 are arranged to enable coils within coil assembly 318 to move the "x-stroke" of stage 208, *i.e.*, a stroke along x-axis 330, within the magnet tracks while maintaining relatively constant force characteristics along y-axis 328.

Beam 310 is mounted on airbearing boxes 348, *e.g.*, x-airbearing boxes 348a and 348b. x-airbearing boxes 348 are similar in structure to y-airbearing box 306. Generally, x-airbearing boxes 348 include air pads 350 which are arranged to substantially contact an "x-beam" (not shown) to enable x-airbearing boxes 348 to slide along the x-beam in an x-direction 330. Air pads 350 are included at the top inner surface and the bottom inner surface of x-airbearing box 348b, *e.g.*, air pads 350d and 350e. In the embodiment as shown, x-airbearing box 348a includes air pads 350 at the top and the bottom inner surfaces, *e.g.*, air pads 350a and 350b, of x-

airbearing box 348a, as well as on the side inner surfaces, *e.g.*, air pad 350c, of x-airbearing box 348a. Air pads 350 will be described below with respect to Figure 4a-c.

X-airbearing boxes 348 are coupled to linear motors which generally include fixed magnets and moving coils 353. Linear motors are arranged to cause airbearing boxes 348 to slide along an x-beam (not shown), or a beam with a longitudinal axis which aligns with x-axis 330. Typically, each motor may be driven with the same force, using different amplifiers and motors. It should be understood, however, that while motors 353 generally do not "match," the differences in motors 353 may be accounted for by controlling the yaw, *e.g.*, angle θz 350, of stage 208.

Typically, the net force from linear motor coils 353 is in the same plane as the center of gravity of stage 208, beam 310, coils 353, airbearing boxes 348, and a coupler 354. Further, the clearance between linear motor coils 352 and their corresponding magnets may be enough to allow a full stroke along z-direction 326 to occur substantially without contact between coils 353 and their respective magnet tracks, *e.g.*, tracks 614 of Figure 6 as will be discussed below.

X-airbearing box 348b may generally support beam 310 through a coupler 354. Coupler 354 may be substantially fixably mounted to both beam 310 and x-airbearing box 348b, and generally includes openings which enable vacuum flow to flow between beam 310 and x-airbearing box 348b. The lack of air pads 350 on the inner side surfaces of x-airbearing box 348b enables x-airbearing box 348b to moving in x-direction 330 and to yaw or otherwise rotate about θz 350. In other words, x-airbearing box 348a is effectively free to only significantly move linearly along x-axis 330 and rotationally about θz 350.

In the described embodiment, in order to allow stage 208 to yaw, *e.g.*, flex or otherwise rotate about z-axis 326, with respect to x-airbearing box 348a, x-airbearing box 348a may be coupled to a yaw flexure 356, in addition to including air pads 350 on each internal surface of x-airbearing box 348a. Yaw flexure 356 may generally be considered to be a one-degree-of-freedom joint, which has one rotational degree of

freedom. In the described embodiment, yaw flexure 356 enables substantially only motion about θz 350, while substantially constraining motion about θx 356 and θy 352, as well as substantially constraining motion along x-axis 330, y-axis 328, and z-axis 326. That is, yaw flexure 356 is arranged to allow a guide beam and x-airbearing box 348b to yaw relative to x-airbearing box 348a.

In general, yaw flexure 356 includes both flexural and rigid members, and is relatively compact. The flexural and rigid members may be separate parts. That is, yaw flexure 356 may be fabricated from multiple parts. However, in one embodiment, yaw flexure 356 may be monolithic, *e.g.*, formed as substantially one part. Typically, yaw flexure 356 may be formed from substantially any suitable material including, but not limited to, metal or ceramic.

As will be appreciated by those skilled in the art, yaw flexure 356 functions substantially as a hinge, and enables yaw to be substantially controlled by linear motors 352. Without yaw flexure 356, any yaw of stage 208 may be constrained by x-airbearing boxes 348 or, more specifically, x-airbearing box 348a. Hence, yawing motions may be likely to be ground out, or, alternatively, yawing motions may not be possible at all. In general, the yaw angle of stage 208 may be controlled by differentially controlling the operation of linear motors associated with coils 353. Such differential control may be achieved, for example, by allowing the linear motors to operate at slightly different speeds.

Coils 353 generally create forces in y-direction 328 in addition to x-direction 330, in order to control the position of reticle stage 208. Specifically, the generation of forces in y-direction 328 facilitates the implementation of a servo feedback loop, coupled with the use of position measurement sensors, to control the position of reticle stage 208.

With reference to Figures 4a-c, y-airbearing box 310 will be described in accordance with an embodiment of the present invention. As previously stated, x-airbearing box 348a is similar in structure to y-airbearing box 310, while x-airbearing box 348b generally differs from y-airbearing box 310 in that x-airbearing box 348b

does not include air pads on each of its internal sides. y-airbearing box 310 is arranged to provide high stiffness, low noise, and substantially no friction while in operation, *e.g.*, moving along beam 310 of Figure 3. Hence, y-airbearing box 310 is suitable for use in a vacuum environment associated with an electron beam projection system.

As shown in Figures 4a-c, y-airbearing box 306 includes air pads 350. In general, air pads 350 are surrounded by channels 404, or grooves. Air pads 350 are typically attached to an air supply, as will be understood by those skilled in the art. The use of multiple channels 404, or air flow evacuation stages, reduces the volume of gas which reaches a vacuum chamber of an electron beam projection system and, as a result, reduces the volume of gas which is pumped out. Therefore, the vacuum environment may remain substantially unaffected by the air associated with y-airbearing box 310.

Channels 404a, which directly surround each air pad 350, are arranged to contain gas which is held at an atmospheric pressure, such that each air pad 350 effectively operates as if each air pad were operating out of a vacuum, *e.g.*, in air. Further, each air pad 350 is in communication with the outside of a vacuum chamber, as for example through ports to a hose. In one embodiment, flow restrictions may be such that a relatively weak vacuum may be applied to the end of such a hose to compensate for flow restrictions. By compensating for flow restrictions, the resulting pressure in channels 404a may be maintained at approximately atmospheric pressure, *e.g.*, between approximately 2 pounds-per-square-inch atmosphere (psia) and approximately 15 psia.

A land 408 separates a channel 404a from channel 404b, which is effectively a low-vacuum pump-out groove. In general, land 408 is substantially the same height as air pad 350. For instance, the height in z-direction 326 of land 408 which is in proximity to air pad 350g of Figure 4c is substantially the same as the height in z-direction 326 of air pad 350g. As such, the gaps between air pads 350 and a guide beam are substantially the same as gaps between lands 408 and the guide beam.

Lands 408 cooperate with such gaps to limit leakage flow from atmospheric channels 404a to low-vacuum channels 404b.

Low-vacuum channels 404b are arranged to be pumped through ports, *e.g.*, low-vacuum transfer ports and ducts in a guide beam, *e.g.*, guide beam 310 of Figure 3, to a device such as a roughing pump. Ducts in the guide beam may be connected to an air supply hose which, in turn, may be coupled to a cable loop which is in fluid communication with a roughing pump. In the described embodiment, a low-vacuum exhaust groove 422, as shown in Figure 4b, is in communication with low-vacuum channels 404b and, further, is substantially contiguous with low-vacuum channels 404b. Exhaust groove 422 may be in communication with the roughing pump through an exhaust port in the guide beam. By way of example, exhaust groove 422 may overlap an exhaust port in the guide beam, which will be described below with respect to Figure 4d, through which low-vacuum flow may be pumped out.

The dimensions of exhaust groove 422 may vary depending upon the requirements of a particular system. Generally, exhaust groove 422 is sufficiently deep, *i.e.*, the dimension of exhaust groove 422 along z-axis 326 is large enough, to allow adequate conductance of low-vacuum flow to the exhaust port in the guide beam. The length of exhaust groove 422, *i.e.*, the dimension of exhaust groove 412 along x-axis 330, may be greater than or substantially equal to approximately the travel of y-airbearing box 306 added to the width of the exhaust port in the guide beam. In other words, exhaust groove 422 is generally sized such that an exhaust port in guide beam 310 is always substantially encompassed by exhaust groove 412. A land 418 is arranged to separate an area 426 from channel 404b and exhaust groove 422. Exhaust groove 420 is arranged to overlap an exhaust port in a guide beam, as for example through a high-vacuum transfer port, to vent high-vacuum flow associated with exhaust groove 420 to a device such as a roughing pump. It should be appreciated that in order to enable both high-vacuum flow and low-vacuum flow to be exhausted into a guide beam, the guide beam may include two ducts, one which is arranged for high-vacuum flow and one which is arranged for low-vacuum flow, as will be discussed below with reference to Figure 4d. Such ducts may be connected to vacuum pumps using any suitable apparatus including, but not limited to, flexible

hoses. In order to enable groove or section 416 to substantially always encompass a high-vacuum transfer port, the stroke of y-airbearing box 306 is generally less than the length, *i.e.*, dimension along y-axis 328, of y-airbearing box 306.

Figure 4d is a diagrammatic three-dimensional representation of a guide beam, *i.e.*, guide beam 310 of Figure 3, in accordance with an embodiment of the present invention. Guide beam 310 includes a low vacuum section 460 and a high vacuum section 462. Low vacuum section 460 includes a port (not shown) which vents low vacuum flow, while high vacuum section 462 includes a port (not shown) which vents high vacuum flow.

Guide beam 310 may generally be formed from substantially any suitable material. Further, the thickness of walls 464 may vary widely depending upon the requirements of a particular system. By way of example, in one embodiment, walls 464 may have a thickness of approximately 15 mm. As shown, guide beam 310 is generally formed as two main pieces 466, which may be bonded using epoxy, *i.e.*, bonded at a bond line 468. Stiffening ribs 470 are included in guide beam 310, as shown, to provide stiffening. In general, stiffening ribs 470, which may be glued, *e.g.*, bonded using epoxy, to protrusions 474 in guide beam 310 are arranged to add damping to guide beam 310 and y-airbearing box 306 as y-airbearing box 306 when bending occurs.

Figure 4e is a diagrammatic side-view representation of coil assembly 318 and cantilever structure 301 of Figure 3. Coil assembly 318 is arranged for coils to move within magnet tracks 502 when cantilever structure 301 is scanning. Magnet tracks 502 are substantially stationary with respect to an electron beam projection system, and are arranged such that coil assembly 318 effectively may not move out of magnet tracks 502. That is, magnet tracks 502 are relatively long along a scanning direction to enable coils assembly 318 to scan within magnet tracks 502 at substantially all times.

In order to prevent a significant yawing motion of cantilever structure 301, coil assembly 318 may be positioned such that a centerline 506 of coil assembly 318

is coincident with the overall center of gravity of cantilever structure 301. It should be understood that in one embodiment, the ability to align centerline 506 with the overall center of gravity of cantilever structure 301 may result in the need to alter the shape of magnet tracks 502. By way of example, the overall shape of magnet tracks 502 may be thickened to accommodate the location of centerline 506.

With reference to Figure 5a, the structure of a guide beam over which x-airbearing box 348b is allowed to move will be described in accordance with an embodiment of the present invention. Guide beam 510 includes a low vacuum side 512 and a high vacuum side 514. Low vacuum side 512 includes low vacuum ports which enable low vacuum flow to be vented between x-airbearing box 348b, coupler 354, and guide beam 310. Similarly, high vacuum side 512 includes high vacuum ports which enable high vacuum flow to be vented between x-airbearing box 348b, coupler 354, and guide beam 310.

Guide beam 510 is arranged to fit through x-airbearing box 348d such that there is a less than approximately 2 mm gap 519 between the sides, *i.e.*, the left side and the right side, of guide beam 510. Such a gap 519 enables x-airbearing box 348d move along x-axis 330 while exhibiting at least a small amount of yaw, *i.e.*, rotation about x-axis 326. Further, gap 519 enables x-airbearing box 348d to exhibit at least a slight motion with respect to y-axis 328.

Figure 5b is a diagrammatic three-dimensional representation of an x-airbearing box, *e.g.*, x-airbearing box 348b of Figure 3, in accordance with an embodiment of the present invention. x-airbearing box 348b includes air pads 350, and is similar to y-airbearing box 306, which was described above with respect to Figures 4a-e. Directly surrounding air pads 350d and 350e, which are coupled to an air supply (not shown) are grooves 524a through which air at an atmospheric pressure is allowed to flow. The air at atmospheric pressure enables air pads 350d and 350e to function substantially as if air pads 350d and 350e were not in a vacuum environment. Lands 526 are arranged to separate atmospheric pressure grooves 524a from low vacuum grooves 524b through which low vacuum flow occurs.

A low vacuum area 530 is coupled to low vacuum grooves 524b, as shown. Both low vacuum area 530 and low vacuum grooves 524b are arranged to enable low vacuum flow to pass between a low vacuum transfer port 536 and low vacuum area 530. In order for the passage of low vacuum flow to occur, ports 516 of guide beam 510, as shown in Figure 5a, are arranged such that ports 516 are always effectively encompassed within low vacuum area 530 during the stroke of x-airbearing box 348d.

A land 527 separates low vacuum grooves 524b from high vacuum grooves 524c, through which high vacuum flow occurs. A high vacuum area 532 is in communication with high vacuum grooves 524c, and is arranged for high vacuum flow to pass between high vacuum area 532, ports 518 of guide beam 510, as shown in Figure 5a, and a high vacuum transfer port 534. During the stroke of x-airbearing box 348d, ports 518 are substantially always encompassed by, *e.g.*, in fluid communication with or contiguous with, high vacuum area 532 to enable high vacuum flow to pass between high vacuum transfer port 534 and high vacuum area 532.

Figure 5c is a three-dimensional diagrammatic representation of a coupler or a beam connector, *e.g.*, coupler 354 of Figure 3, in accordance with an embodiment of the present invention. Coupler 354 includes a low vacuum channel 540 and a high vacuum channel 544. Low vacuum channel 540 is arranged to be in fluid communication with low vacuum section 460 of guide beam 310 of Figure 4d and with low vacuum transfer port 536 of Figure 5b. Similarly, high vacuum channel 544 is arranged to be in fluid communication with high vacuum section 462 of guide beam 310, as well as with high vacuum transfer port 534 of Figure 5b. In other words, coupler 354 enables vacuum flow to occur between guide beam 310 and x-airbearing box 348b.

Referring next to Figures 5d and 5e, an x-airbearing box with air pads on all inner sides and a guide beam which is suitable for use with the x-airbearing box will be described. Specifically, one embodiment of a guide beam that is suitable for use with x-airbearing box 348a of Figure 3 will be described in accordance with the present invention. A guide beam 570, over or around which x-airbearing box 348a

may move, includes a low vacuum section 572 and a high vacuum section 574. Low vacuum section 572 includes a low vacuum exhaust port 576 through which low vacuum flow travels. Similarly, high vacuum section 574 includes a high vacuum exhaust port through which high vacuum flow travels.

X-airbearing box 348a includes air pads 350 on all four sides. As such, x-airbearing box 358a is effectively constrained to move substantially only along x-axis 330. In order to allow for some yawing movement of x-airbearing box 348a, yaw flexure 356 is coupled to x-airbearing box 348a. Air pads 350a and 350c are generally coupled to an air supply, and are each surrounded by a groove 582a through which air at an atmospheric pressure flows. As mentioned above, grooves 582a enable air pads 350a and 350c to operate as it air pads 350a and 350c were not in a vacuum environment.

Grooves 582a are separated from low vacuum grooves 582b by lands 588. The low vacuum flow associated with grooves 582b are, in turn, separated from high vacuum grooves 582c by lands 590. Grooves 582b are contiguous with areas 586. That is, the low vacuum flow associated with grooves 582b is also associated with areas 586. In one embodiment, low vacuum exhaust port 576 is always in fluid communication with areas 586. Hence, the stroke of x-airbearing box 348a is maintained such that low vacuum exhaust port 576 overlaps areas 586. Grooves 582c are contiguous with a high vacuum area 584 which, in turn, is arranged to be overlapped by high vacuum exhaust port 578 during the stroke of x-airbearing box 348a.

Figure 6 is a three-dimensional representation of a scanning system which includes reticle stage 208 and, hence, cantilever structure 301, in accordance with an embodiment of the present invention. As shown, within a scanning system 602, cantilever structure 301 includes y-airbearing box 306 which substantially surrounds beam 310. Beam 310 is coupled through yaw flexure 356 to x-airbearing box 348a, which is arranged to scan along a dual-chambered beam 570. Beam 310 is also coupled to x-airbearing box 348b, which is arranged to scan along a dual-chambered beam 510, through coupler 354, as was discussed above.

In general, y-airbearing box 306 moves with respect to magnet tracks 502 which, together with coils (not shown) that are coupled to y-airbearing box 306, effectively form a linear motor. As described above with respect to Figure 5, coils move within magnet tracks 502. Similarly, x-airbearing boxes 348 have coils 352 which move within magnet tracks 614 to cause x-airbearing boxes 348 to scan along beams 510 and 570.

In order to enable reticle plate 208 to be stepped in z-direction 326, beams 510 and 570 may be coupled, *e.g.*, at a front edge, to lifting mechanisms 630. Lifting mechanisms 630 are generally arranged to lift beams 510 and 570 and, as a result, reticle plate 208 in z-direction 326. Lifting mechanisms 630 may be of substantially any suitable configuration. By way of example, lifting mechanisms 630 may include actuators which use air springs or other mechanical springs to offset the weight of scanning system 600. As will be understood by those skilled in the art, actuators are often either voice coil motors or EI core motors.

The overall design of a scanning system which incorporates a reticle stage may vary. For instance, the use of a yaw flexure such as yaw flexure 356 of Figure 3 may be eliminated. When the use of a yaw flexure is eliminated, a servo motor may be implemented to substantially control the position of a reticle stage along a scanning directions, and x-bearing boxes may be altered to compensate for the lack of a yaw flexure. With reference to Figure 7, a scanning system which does not include a yaw flexure will be described in accordance with a second embodiment of the present invention. A scanning system 702 includes a stage 708 which has a y-airbearing box 710 and a reticle plate 712. Y-airbearing box 710 is substantially the same as y-airbearing box 306, which was described above in detail with respect to Figures 4a-4e. Reticle plate 712, which is similar to reticle plate 300 of Figure 3, includes two openings 714 that are arranged to support and to accommodate wafers, although it should be appreciated that the number of openings 714 in reticle plate 712 may be widely varied.

Y-airbearing box 710 is arranged to scan along a beam 711 in a y-direction 728, and coils (not shown) which are generally coupled to y-airbearing box 710 may move within magnet tracks 732. As will be appreciated by those skilled in the art, coils together with magnet tracks 732 effectively form a linear motor. Magnet tracks 732 are suspended, in one embodiment, on flexures 735. Even while suspended on flexures 735, magnet tracks 732 are substantially constrained from moving enough to disturb an overall magnetic field about scanning system 702.

Beam 711 is coupled to x-airbearing boxes 718, which are arranged to scan along dual-chambered beams 720, through couplers 722. In the described embodiment, as no yaw flexures are used, yaw may be substantially controlled through the use of motors 724 which causes reticle plate 712 to move along an x-axis 730. Specifically, motors 724 are effectively linear motors for causing motion along x-axis 730 with additional linear motors, *e.g.*, additional coils and magnets, for controlling motion along a y-axis 728.

X-airbearing boxes 718 are similar in configuration to x-airbearing box 348b of Figures 5a and 5b, *i.e.*, there are no air pads on the inner side surfaces of x-airbearing boxes 718. Such a configuration may be used for x-airbearing boxes 718 as there is substantially no constraint on x-airbearing boxes 718 in y-direction 328, and the alignment of x-airbearing boxes 718 with respect to beams 720 is less critical than would be the case if a yaw flexure were included in scanning system 602. .

In general, y-airbearing box 306 moves with respect to magnet tracks 502 which, together with coils (not shown) that are coupled to y-airbearing box 306, effectively form a linear motor. As described above with respect to Figure 5, coils move within magnet tracks 502. Similarly, x-airbearing boxes 348 have coils 352 which move within magnet tracks 614 to cause x-airbearing boxes 348 to scan along beams 510 and 570.

Referring again to Figure 7, lifting mechanisms 734 are generally arranged to step reticle plate 712 in a z-direction 726, and may include actuators, *e.g.*, voice coil motors or EI core motors, which use air springs or other mechanical springs to offset

the weight of scanning system 702. Scanning system 702 also includes a joiner 740 which is arranged to cause a reaction force to be dispersed. The reaction force, as will be appreciated by those skilled in the art, is typically created in response to the drive created by linear motors.

Scanning system 702 may include any number of sensors which are arranged to measure the position of various components of scanning system 702. Surfaces 742, 744, 746, 748 may be mirrored such that laser interferometers may be used to measure relative positions of the various components. By way of example, laser interferometer beams may be reflected off of surface 744 to measure a linear position of reticle plate 712 along x-axis 730, as well as rotational positions about y-axis 728 and z-axis 726. Laser interferometer beams may also be reflected off of surface 746 to measure a linear position of reticle plate 712 along y-axis 728, and rotational positions about z-axis 726 and x-axis 730.

Surfaces 742, 748 may be used to measure positions of plate 712. For example, laser interferometer beams may reflect off of surfaces 742, 748 such that the position of plate 712 with respect to x-axis 730 and the rotation of plate 712 with respect to z-axis 726 may be determined.

In order to measure a position with respect to y-axis 728 of plate 712, position sensors may be placed such that at least one of a leading or trailing edge of plate 712, with respect to y-axis 728, may be monitored. Further, an autofocus sensor may be added beneath reticle plate 712 to measure the position of reticle plate 712 along z-axis 726. Finally, in some embodiments, sensors may be implemented with respect to lifting mechanisms 734 to measure the extension of springs within lifting mechanisms 734, for example, along z-axis 726.

Figure 8 is a three-dimensional representation the back of scanning system 702 in accordance with the second embodiment of the present invention. As will be appreciated by those familiar with the art, scanning systems that support a reticle stage in electron beam photolithography systems are typically positioned within a vacuum chamber (not shown). Bellows (not shown) are often used to seal around

components that penetrate the vacuum chamber. One component that typically must penetrate the vacuum chamber is the magnetic track 502. Since the pressure outside the vacuum chamber (typically at atmospheric pressure) is substantially higher than the pressure inside the chamber (close to a vacuum), there can be a significant force that biases the magnetic track during operation. One way to balance this force on the magnetic tracks is to provide reaction force links 802 which are coupled to joiner 740. The opposite ends 803 of the reaction force links 802 may then be coupled to bellows (not shown) that are sized appropriately to balance any external air pressure forces applied to the magnetic track. Similar reaction force links 804 can be provided for the magnetic tracks 732 that control movements in the x-direction 730. In general, reaction force links 802 and reaction force links 804, are arranged to balance external forces that may be applied to the various magnetic tracks.

Cable loops 810, 820 are arranged to provide power to linear motors. Specifically, cable loop 810 is arranged to provide power to linear motors 724 while cable loop 820 is arranged to provide power to the linear motor that includes magnet track 732. A cable track 822 is arranged to accommodate cable loops 810, 822 to provide power through cable loops 810, 822.

Although only a few embodiments of the present invention have been described, it should be understood that the present invention may be embodied in many other specific forms without departing from the spirit or the scope of the present invention. By way of example, while a reticle stage may be formed as a hollow ceramic structure, the reticle stage may also be formed from a variety of other materials. Suitable materials may include, but are not limited to, plastics and woods.

The design of airbearings for use in a scanning system of the present invention has been described as including air pads and various channels for vacuum flow. It should be appreciated that the configuration of airbearing described above is just one example of airbearings which are suitable for use in a relatively high vacuum environment. Further, the design of the airbearings may vary from the design described above without departing from the spirit or the scope of the present invention.

The beams, or guide beams, of the present invention are generally dual-chambered. Both the design of the dual-chambered beams and dimensions of the dual-chambered beams may be widely varied. By way of example, a beam which is aligned along a y-axis, *e.g.*, a y-beam, may have a wall thickness of approximately 15 millimeters (mm), and be dual-chambered such that a top chamber is associated with a low vacuum flow and a bottom chamber is associated with a high vacuum flow. A y-beam may also be reinforced using stiffening ribs, bonded to the y-beam using epoxy, which are positioned beneath where air pads from a y-airbearing box would contact the y-beam. The dual-chambered x-beams of a scanning system which does not include a yaw flexure may have high vacuum and low vacuum chambers which are side-by-side, thereby facilitating the flow between a y-beam and the x-beams through couplers, or beam connectors.

While a cantilevered reticle plate has been described as being suitable for use as a part of an electron beam projection system, it should be understood that a cantilevered reticle plate may generally be used in substantially any suitable application. For instance, a cantilevered reticle plate may be implemented for use with a conventional optical lithography system.

In the discussions of the various embodiments, the work piece holder has been described in the context of a reticle stage (e.g. 208) having reticle plates (e.g. 300, 712) arranged to one or more reticles. However, it should be appreciated that exactly the same structure can be used to support a wafer stage or other devices in a lithography apparatus. For example, the plates may be designed to support one or more wafers as opposed to the reticles thereby making the stage a "wafer stage" as opposed to a "reticle stage." Therefore, the present examples are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope of the appended claims.